

Laboratory Modeling of Internal Wave Generation in Straits

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LONG-TERM GOALS

The long term goal is to use a combination of laboratory and theoretical modeling to provide insight into the generation of the internal tide at the Luzon Strait. Ultimately, in combination with other reserach projects in the DRI, this will lead to an improved predictive capability for the timing and amplitude of nonlinear internal waves in the South China Sea.

OBJECTIVES

A specific objective is to clearly demonstrate that the mechanism resposnsible for the generation of large amplitude solitary waves in the South China Sea is associated with the steepening of a weakly nonlinear internal tide, as opposed to generation by a topographic hot spot with the Luzon Strait. Another objective is to produce a simple software tool for reasonably calculating internal tide generation for realistic topography and background stratification.

APPROACH

The approach is to use Green function analysis to develop a thorough appreication of the complexity and governing parameters regarding internal tide generation by a complex topogrtaphic system in realistic stratifications. This is complemented by performace of an unprecedented internal tide generation experiment at the Coriolis platform, using an arrangment that reasonably reproduced the key dimensionless dynamical parameters relevant to the ocean. Most of the work has been carried out by a postdoc, Matthieu Mercier, under the supervision of the PI.

WORK COMPLETED

The experiments were completed early on in the project and much of the ensuing work has involved processing, analysis, interpretation and quality checking of the data. The key results regarding M_2 internal tide generation have been completed and submitted for publication. The Green function code has been documented with examples and made freely available to oceanographers through the PI's website.

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RESULTS

The key result is unambiguous verification that the Luzon Strait, despite all its complexity, produces an internal tide that is directed towards the west-northwest and this internal tide is dominated by mode-1. Furthermore, the mode-1 internal tide is sufficiently nonlinear that it will steepen, even in the presence of background rotation, to form the solitary waves that are observed in the South China Sea.

Figure 1(a) presents a snapshot of the velocity field in the plane $z = -0.04\text{m}$, with instantaneous velocity vectors inside the M_2 filtered tidal ellipses. This view essentially contains the baroclinic velocity component by virtue of considering the time instant of flow reversal of the barotropic tide (i.e. the onset of flow from the SCS to the PO). Large-scale coherent waves radiate from the strait in a west-northwest direction. The maps of the amplitude and phase of the M_2 -filtered baroclinic and barotropic tides, which cannot be readily discriminated, are presented in figure 1(b) and (c), respectively. There is a modulation of the amplitude oriented in the 285°N direction, which is not due to interference with internal waves reflected at the wall of the tank, as no signal was observed in the SCS when filtering solely eastward propagating waves (Mercier *et al.*, 2008). The apparent wavelength of the signal, $\sim 1.3\text{m}$, is consistent with an internal tide dominated by the mode-1 wavelength of 1.4m for this stratification. A notable feature in figure 1(c) is that a wave front, evident as a sharp line of constant phase, connects coherently from the central and southern sections of the eastern ridge to the far field west of both ridges, on the way smoothly adjoining the phase of the wave field generated by the northern and central sections of the western ridge; the combined wave front coming from these sections of the two ridges propagates in a $\sim 285^\circ\text{N}$ direction. In the northern section of the strait, between the two ridges, no clear phase propagation exists, a behavior characteristic of a standing wave pattern. In the absence of background rotation, although the wavelength of the radiated internal tide is noticeably diminished, we found little discernible change in the direction of radiation, revealing the dominant role of the topography in shaping the radiated M_2 internal tide. Figure 1(d) presents the same data as in figure 1(a), but for a vertical transect indicated by the blue dashed line. The structure of the velocity field takes the form of a classic mode-1 signal, with a vertical velocity maxima of alternating signs along the length of the transect and in the vicinity of the pycnocline, as expected from the observations in figure 1(a). Modal decomposition confirms these results, determining that $\sim 95\%$ of the energy flux is in mode-1, and the remaining 5% in modes 2 and 3 mainly.

Although the ISWs in the SCS are best described by fully nonlinear models (Li and Farmer, 2011), in order to reasonably quantify nonlinearity we assume the waves to be governed by a weakly nonlinear, KdV-like equation. The nonlinearity of the wave field is assessed by the ratio ζ/H (it is appropriate to scale with H since the waves are dominantly mode-1), where ζ is a measure of the wave amplitude given by $\eta(x,z,t) = \zeta(x,t)\phi(z)$, η being the vertical displacement of an isopycnal initially located at (x,z) , and ϕ the long wave vertical structure function of mode-1 evaluated at the initial depth of the isopycnal. Estimations of ζ/H are based on time series presented in Fig. 2, extracted at $z = -3.6\text{ cm}$ and coordinates $(20.5^\circ\text{N}, 120.5^\circ\text{E})$. Given the stratification profile, η is obtained from the CT probe recordings of the density perturbation, ρ' in Fig. 2(a). The vertical velocity estimated from the vertical displacement ($d\eta/dt$) is compared with the vertical velocity (W) obtained from PIV measurements in Fig. 2(b), showing a good correlation between the two signals, although stronger nonlinear oscillations are observed in $d\eta/dt$. The east-west barotropic and total velocities, U_{bt} and U respectively, are also displayed to indicate the linear nature of the barotropic tide and the dominant baroclinic contribution in the total velocity. Finally, the time series of ζ/H in Fig. 4(c) shows that the wave amplitude is $\sim 5\%$ of

the water height. This is consistent with the assumption of weak non-linearity and in good agreement with oceanic observations and a recent analysis of Li and Farmer (2011) based upon the rotationally-modified KdV equation.

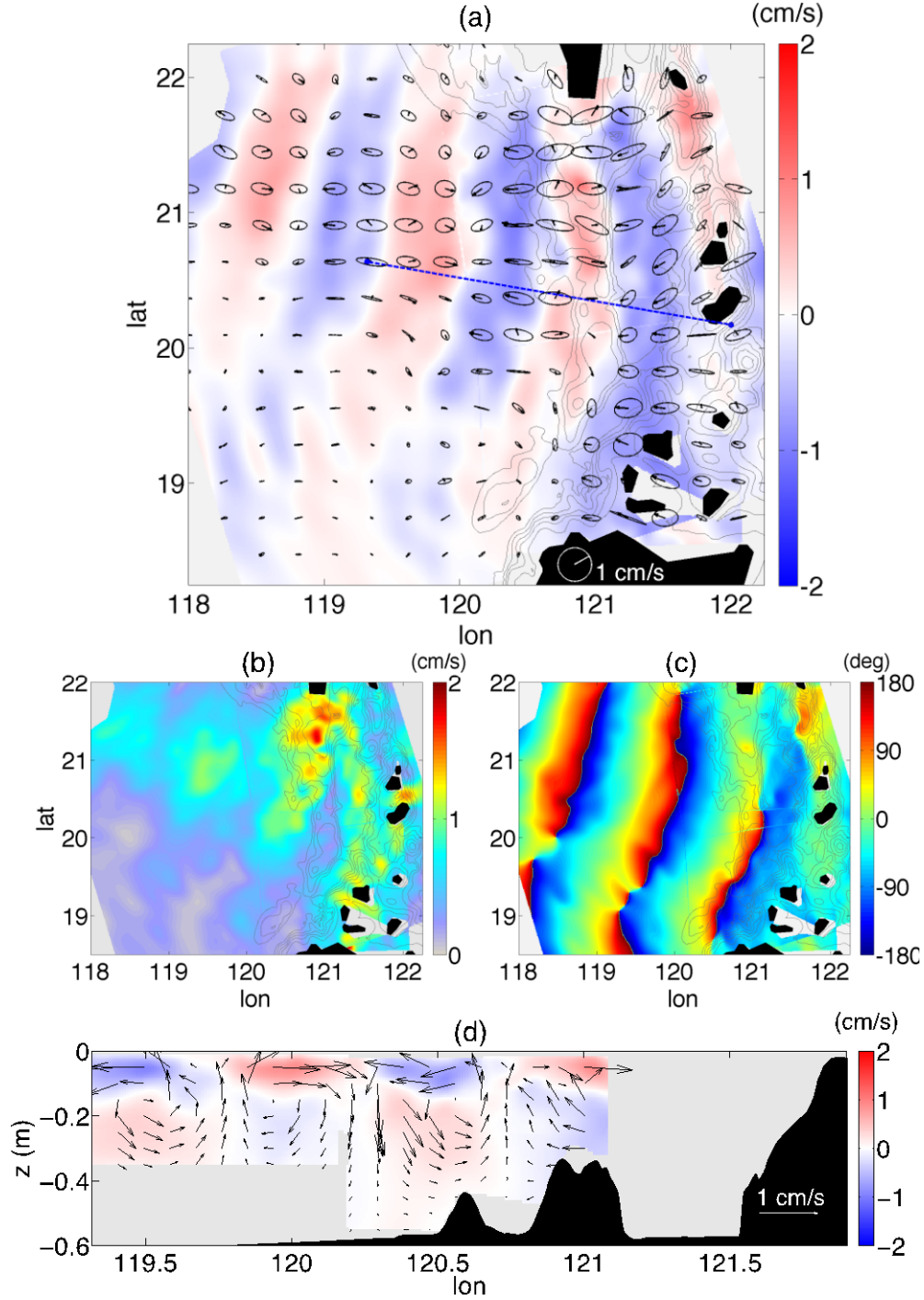


Figure 1: (a) Colormap of the east-west velocity in the isopycnal plane at $z = -0.04\text{m}$ at an instant of barotropic tide flow reversal. The local velocity direction is indicated by the black arrows inside the tidal ellipses. (b) Amplitude of the total velocity and (c) phase of the east-west velocity of the combined M_2 baroclinic and barotropic tides, filtered at the forcing frequency. (d) Same data as in (a) for the vertical transect indicated by the dashed blue line in (a), arrows indicate the in-plane velocity field.

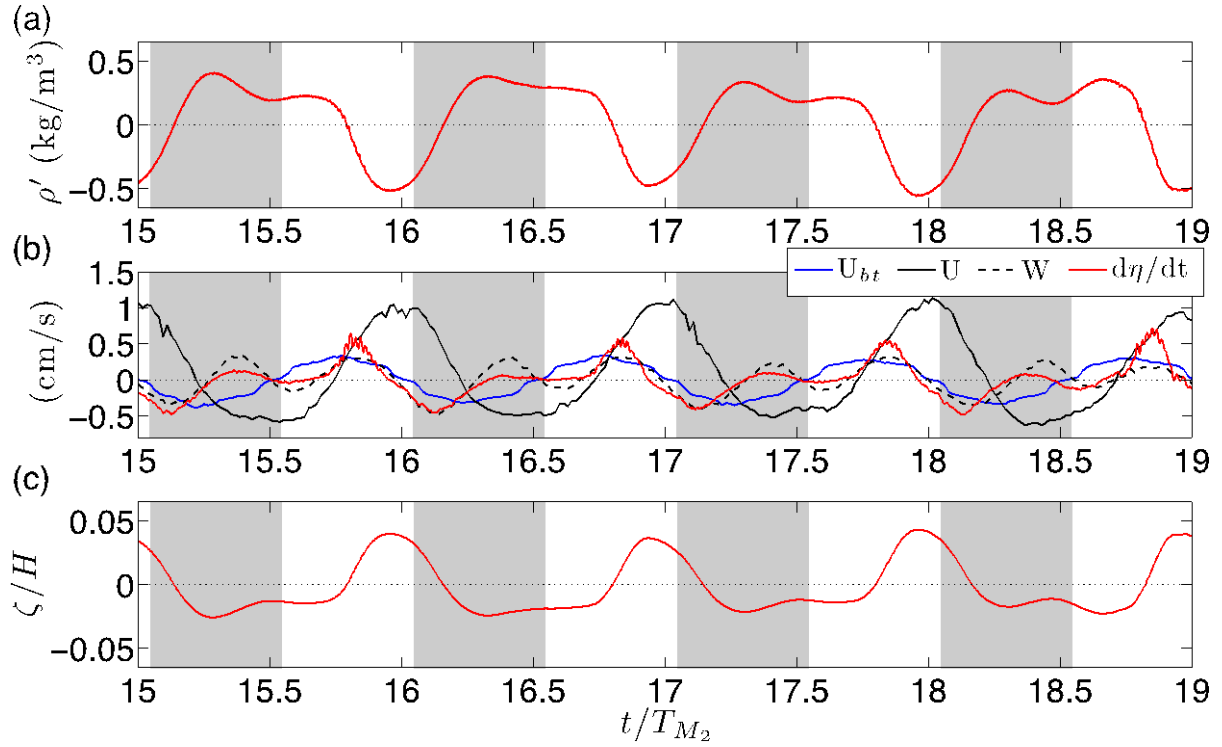


Figure 2: Time series of (a) density perturbations from a conductivity probe located at $z = -3.6\text{cm}$ and coordinates $(20.5^\circ\text{N}, 120.5^\circ\text{E})$; (b) the east-west and vertical velocity (U and W respectively) at the same location, along with the barotropic east-west velocity U_{bt} (experiments with no stratification) and the vertical velocity $d\eta/dt$ estimated from the vertical displacements η and (c) the nonlinear first internal mode amplitude ζ compared to the water depth H . Gray (resp. white) regions correspond to flow from PO to SCS (resp. SCS to PO)

TRANSITIONS

The software *iTides* is hosted on the PIs website (<http://web.mit.edu/endlab>) and is being used by several members of the IWISE to calculate internal tide generation. A screenshot of the *iTides* host page is shown in figure 3, below.

RELATED PROJECTS

None

REFERENCES

Li, Q., and D.M. Farmer (2011), The generation and evolution of nonlinear internal waves in the deep basin of the South China Sea, *J. Phys. Oceanogr.*, **41**, 1345-1363.

Mercier, M.J., N.B. Garnier, and T.Dauxois (2008), Reflection and diffraction of internal waves analyzed with the Hilbert transform, *Phys. Fluids*, **20**, 086601.



Figure 3: A screen shot of the iTides website.

PUBLICATIONS

M. Mercier et al. (2013), Large-scale, realistic laboratory modeling of M_2 internal tide generation at the Luzon Strait, *Geophys. Res. Lett.*, in review.